

# Analysis of Simulated Image Sequences from Sensors for Restricted-Visibility Operations

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## Abstract

As part of the Advanced SenSor and Imaging System Technology (ASSIST) program, imaging systems and interface requirements are being evaluated in order to enhance a pilot's view of the outside environment under restricted visibility conditions. A sequence of simulated images as seen from an aircraft as it approaches a runway was obtained from a model of a passive millimeter wave sensor operating at 94 GHz. Atmospheric attenuation is known to be a local minimum at this frequency. These images were analyzed to delineate objects of interest such as runways, taxiways, buildings, etc. Information about the position and motion of various objects on the ground may be computed by tracking the regions in such segmented image sequence. This information can be combined with data from other sensors to alert the pilots of any objects which are likely to be a hazard for continuing the flight.

## 1. Introduction

Enhancing the safety of operation of aircraft under restricted visibility conditions has been an important research topic for many years [1]. There is a great deal of interest in imaging sensors with the capability to *see through* fog and produce a *real-world* display which, when combined with symbolic or pictorial guidance information, could provide the basis for a landing system with lower visual minimum capability than those presently being used operationally [2]. An example of the interest in sensor and imaging systems technology is the FAA/DOD/Industry program entitled, *Synthetic Vision* [3].

Since the attenuation of radiation in the visible spectrum due to fog is very large [4] (Figure 1), sensors are being designed to operate at lower frequencies at which the attenuation is smaller (providing the ability to *see through* fog). One such frequency of choice is 94 GHz since the clear-air attenuation at this frequency is a local minimum and fog attenuation is low (Figure 1). In a joint research project, NASA Langley Research Center and TRW are developing an imaging system to capture images using a passive sensor operating at this frequency. The goal of this project is to establish a foundation for imaging sensor and pictorial graphics display technology and their integration into future cockpit systems to enable transport operations under restricted-visibility conditions [2]. Extensive enhancement and analysis of images acquired using such sensors is essential in order to identify and track various objects such as buildings, runways, vehicles, etc. as the aircraft approaches a runway for landing. Information extracted from such an analysis is useful to generate warning signals to the pilot of any potential hazards.

A real-time model of the visible output from a 94 GHz sensor, based on a radiometric simulation of the sensor, has been developed. A sequence of images as seen from an aircraft as it approaches for landing has been simulated using this model. Thirty frames from this sequence of 200 x 200 pixel images (For: H x V) were analyzed to identify and track objects in the image using the *Cantata* image processing package within the visual programming environment provided by the *Khoros* software system [5]. The image analysis operations are described in this paper.

## 2. Analysis of Simulated Images

The image analysis operations include noise filtering, edge detection, edge closing, region labeling, and matching of corresponding objects in the image sequence. An example of the iconic *Cantata* workspace used in this analysis is shown in Figure 2. Three frames from the simulated image sequence on which this analysis was performed are shown in Figure 3. The image analysis operations are described in this section.

**Noise Filtering:** Since a model for the noise phenomena is not yet available, random noise was added to the images during simulation. A simple weighted spatial averaging filter (module marked *vconvolve* in Fig. 2) [6] was then used to decrease the effect of this additive noise. Although this is adequate to filter noise in these simulated images, a filter designed to match the noise in actual, real-world images will have to be developed later, when such data is available.

**Edge Detection:** Edge pixels in the images were detected using the Difference Recursive Filter (DRF; *wdrf* in Fig. 2) [7]. This filter, which is based on principles similar to those of the well-known Laplacian of Gaussian filter [8], has been shown to be an optimal filter for detection of step edges in white noise [7]. The smoothing function used by this filter is a symmetrical exponential function.

**Edge Closing:** Edge pixels detected by the DRF filter are not guaranteed to form closed object boundaries. Such gaps in boundaries are bridged using an edge-closing operator (*vclose* in Fig. 2). The edge-closing operator uses as its input two images: the output of the DRF filter and a gradient image (eg., output of a Sobel edge detector - *wdiff* in Fig. 2). It follows a path of maximum gradient between the two end points being bridged. The resulting closed edges detected in corresponding images of Figure 3 are shown in Figure 4.

**Region Labeling:** Connected pixels belonging to the same object in the image are given a unique label. 4-connectivity [6] is used in this labeling scheme (pixels which are connected at the top, bottom, left, and right - but not diagonally - are said to be four-connected to the pixel at the center). The region labeling operator (*vlabel* in Fig. 2) uses the output of the edge-closing module; alternatively, it is also possible to label objects by operating directly on the noise filtered image using region growing techniques.

**Region Matching:** Objects in consecutive frames of the image sequence are compared to identify corresponding objects. The matching (*vrmatch* in Fig. 2) is done using a probabilistic rule which is based on the size and shape of regions. It computes the similarity of objects in successive frames. To illustrate objects which are matched they are assigned the same gray level in both frames in the displayed image. Two such frames after matching are shown in Figure 5.

### 3. Conclusions

A software system for analyzing simulated image sequences from a passive millimeter wave imaging system was described in this paper. The analysis/tracking system consists of the following stages: smoothing using a spatial averaging filter for noise reduction; detection of edge pixels using a recursive filter; bridging discontinuities in detected edges using an edge-linking operator; labeling objects in each image in the sequence; and comparing objects in consecutive frames to locate corresponding objects.

The passive millimeter wave imaging system will facilitate operation in restricted visibility conditions. Automated analysis of sensor-captured images to locate and track moving objects will provide critical information necessary for detecting potential runway incursions. Quantifying the amount of apparent motion of static objects in the scene from consecutive image frames is also useful as a cross-check of the position and velocity of the approaching aircraft. The preliminary results presented here using simulated images clearly demonstrate the potential of image analysis methods for detecting and tracking objects in a dynamic scene. Analysis of real images is well known to be a much more difficult task, however, particularly in real-time. To realize a practical system, new vision algorithms for analyzing sensor-captured images, and new display concepts for fusing information from various sensors, are necessary.

### References

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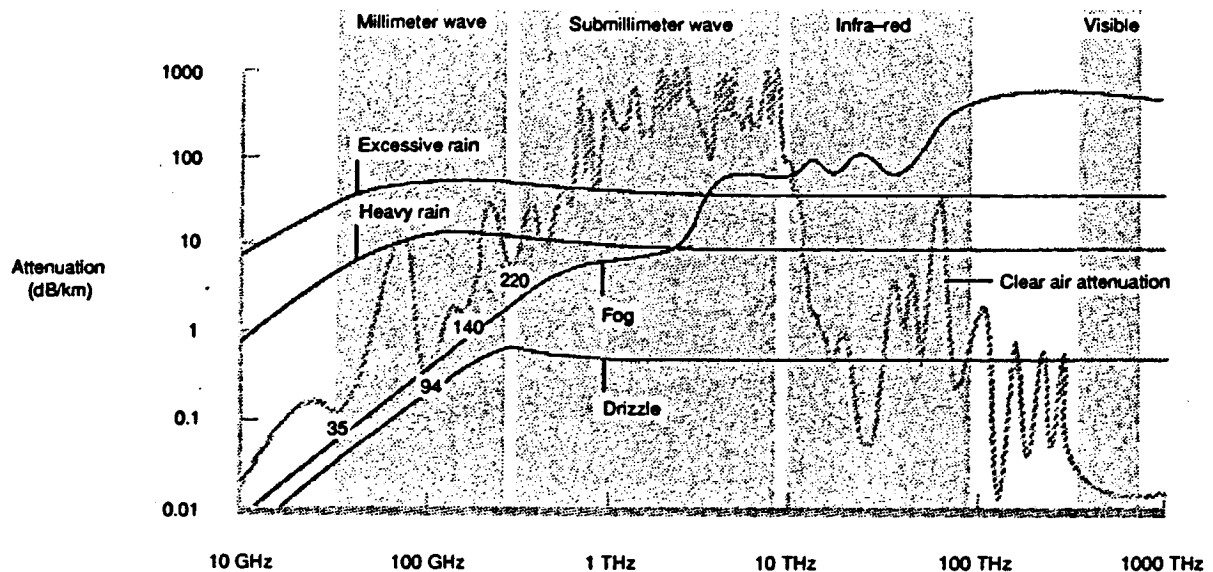


Figure 1. Atmospheric effects on electromagnetic radiation [4].

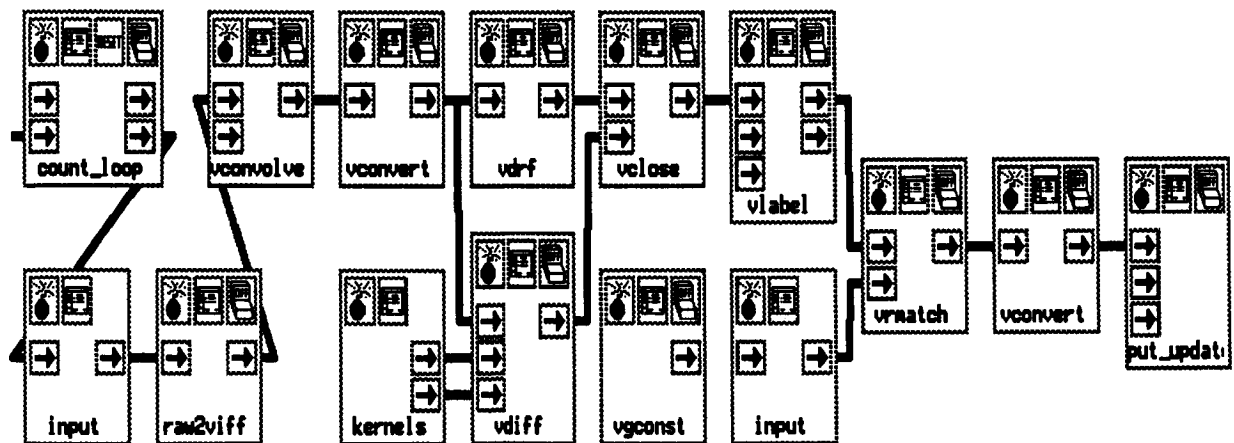


Figure 2. Block diagram of the image analysis and tracking operations presented as a *Cantata* workspace.

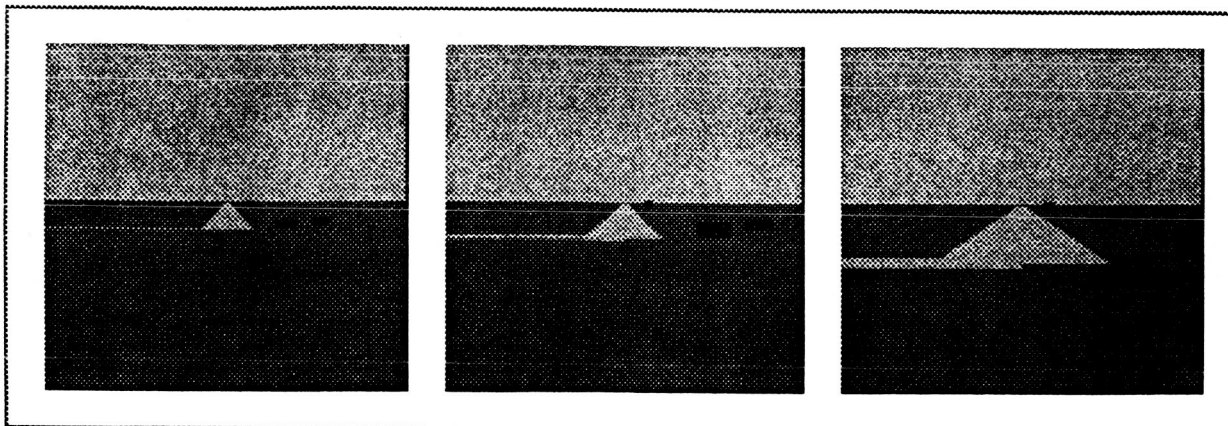


Figure 3. Frames 1, 16, and 30 in the sequence of simulated images.

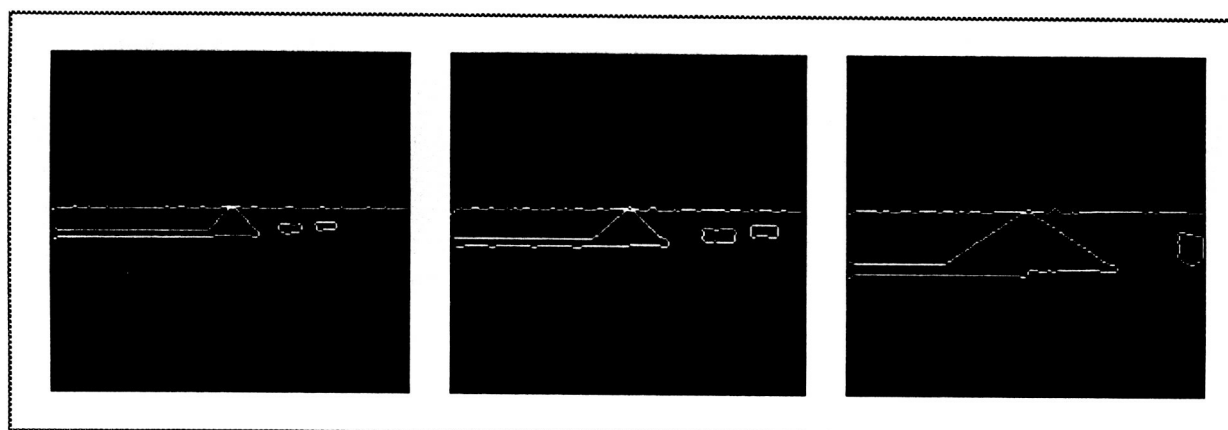


Figure 4. Runway, taxiway, horizon, and buildings delineated in the images of Figure 3.

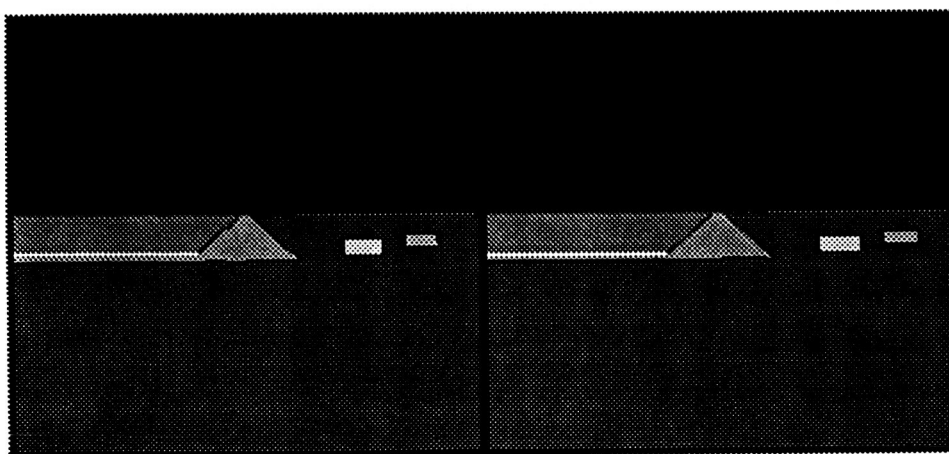


Figure 5. Two consecutive frames in the image sequence after detection and tracking of objects; corresponding objects in the two images are given the same gray level.